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Study on Flow Unit of Heavy Oil Bottom Water Reservoir with Over-Limited Thickness in Offshore Oilfield

Wei Wang*, Jie Tan, Songru Mu, Bo Li, Wentong Zhang

Bohai Oilfield Research Institute of CNOOC Ltd., Tianjin Branch, Tianjin, China
Email: *wangwei16@cnooc.com.cn

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Abstract

The upper Ming section of L oilfield is a typical offshore heavy oil bottom-water reservoir with thick fluvial layers. All horizontal wells are developed by natural energy. Due to the few drilling holes and influence by the resolution of seismic data, it is difficult to describe reservoirs with thickness over 20 meters. In this paper, seismic resonance amplitude inversion technology is introduced to restore the real response of thick reservoirs and interbeds by drilling and drilling verification, and the geological bodies with different thickness are displayed by frequency division RGB three primary colors. Flow units of heavy oil reservoirs with bottom water are divided according to the three major factors of interlayer, lithologic internal boundary and water-oil thickness ratio which have the greatest influence on horizontal well development, thick sand bodies are divided into 10 different flow units in three levels, each unit is separated from each other, and the reservoir structure, water-cut characteristics and water-flooding characteristics are different. The reliability of the research is improved by using the dynamic data of horizontal wells and newly drilled passing wells, which provides a basis for tapping the potential of heavy oil reservoirs with bottom water.

Keywords

Over-Limited Thick Layer, Inversion of Tuned Amplitude, Frequency Division RGB Fusion, Water-Oil Thickness Ratio, Flow Unit

1. Introduction

Since Hearn C.L. put forward the concept of flow unit in 1984, [1] [2], many scholars have expanded the concept by studying reservoir characterization and reservoir evaluation. Relevant studies [3] consider that under the condition of similar reservoir rock properties and physical properties, the characteristics of reservoir structure, fluid properties and remaining oil distribution are similar, and there is no geological unit with fault and lithology affecting oil-water flow. It is called "flow unit". The study of flow unit is the key to fine reservoir description and the main goal of development and adjustment. The concept of flow unit and the formation and development of its research methods provide an effective means for understanding reservoir heterogeneity. The study of flow units is a further deepening of the study of reservoir configuration, which combines the distribution of reservoir configuration, the division of flow units and the distribution of remaining oil. From the above definition, we can see that this concept can solve the problem of subdivision of thick reservoir and existing small reservoir well according to different scales, which is of great significance for tapping potential and detailed description of oilfield. At present, there are two main methods for dividing flow units at home and abroad: 1) Physical property dividing method. This method chooses drilling parameters such as porosity, permeability, particle size, shale content and so on, and carries out quantitative dividing of flow units between wells by cluster analysis and random simulation, which requires very high sample points. 2) The second method is lithofacies analysis. On the basis of cycle division and correlation, the reservoir sedimentary thickness and lithologic boundary are discussed, which can be divided into four scales: large, medium, small and micro. According to the degree of core research, it can be precise to micro scale. Because the following studies on fluvial oilfields in domestic offshore oilfields are typical high porosity and permeability oilfields with few drilling wells and high core cost, lithofacies analysis method should be adopted mainly according to commonly used seismic data, which is limited by the resolution of seismic data from thick reservoirs. At present, domestic research scale is too large and uncertain. Therefore, starting from the original seismic data, this paper dissects the frequency. Data, frequency division method is used to study the distribution characteristics of this seemingly "sand-filled" reservoir, which is rarely reported at home and abroad.

Offshore oilfields mainly consist of thick-bed heavy oil and bottom water reservoirs of fluvial facies. The reservoir thickness generally exceeds 20 m. Because of multi-stage channel overlapping, it is difficult to precisely split the drilling wells. Many years of production practice has proved that the distribution of residual oil in this pan-connected body is very complex, and it is necessary to carry out flow unit research to improve the development effect. At present, scholars at home and abroad have done a lot of research on the formation mechanism and control factors of flow units from different perspectives. Many research methods have been put forward by analyzing a large number of drilling data. The development cost of offshore oilfields is high and most of them are horizontal wells. Taking L oilfield as an example, starting from the original earthquake, this paper discusses the flow unit research method of combining frequency division method with bottom water reservoir attributes under the condition of few wells in offshore oilfields. The main contribution of this paper is to break through the limitation of large-scale and uncertain original seismic data, to dissect deep frequency data, to study the distribution characteristics of residual oil in water cut rising and passing wells according to the development practice of all horizontal wells in the oilfield, to carry out the study of flow units under the condition of large offshore well spacing, and to open up a new way for tapping potential remaining oilfields or even comprehensive adjustment in the later period. However, due to the different characteristics of the original seismic data in different oilfields, this paper still has further improvement. Later, we can analyze the applicability and differences of this method in different oilfields, and fundamentally put forward suggestions for seismic re-acquisition, but this method can be popularized and applied in ultra-thick layers [4] [5].

2. The Survey of Oilfield

The upper Ming member of L oilfield is a typical meandering river shallow water delta deposit in the sea. The long-term base level decline has resulted in the formation of overlapping foliated thick sand bodies [6]. The average thickness of Um797 sand body reservoir in the main horizon is more than 20 m. During this period, there were obvious transgressive deposits. Early sand bodies developed, showing a "pan-connected body". Later, the range of sand bodies gradually decreased, and the river action was obvious. According to mudstone color of mudstone, it is inferred that shallow water sediment is dominant in the west, delta plain sediment is dominant in the east, and abandoned rivers are developed in some areas (**Figure 1**). Dual actions of Lake waves and rivers result in overlapping and continuous sand bodies, which change rapidly in transverse direction and develop unevenly in thickness (**Figure 2**). In the early stage, seven horizontal wells were deployed in the sand body, and the difference was obvious. The water cut of horizontal wells in typical bottom water area exceeded 90% in three months, but the production of different thickness of bottom water was slightly different; the water cut of horizontal wells in interlayer developed area exceeded 90% in eight months; while in the Eastern part, the typical edge

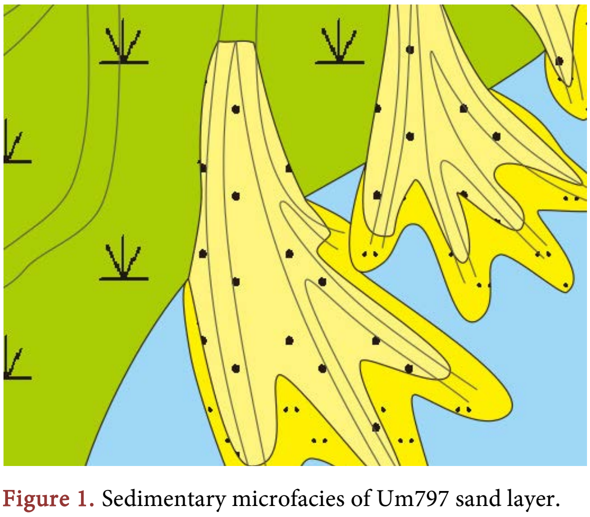

Figure 1. Sedimentary microfacies of Um797 sand layer.

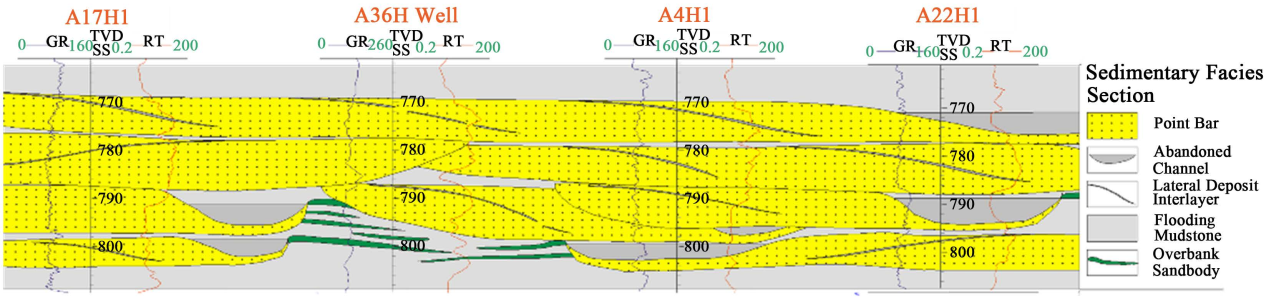

Figure 2. Fine contrast profile of Um797 sand layer.

water area was typical edge water area with strong River action, which was a single channel reservoir, and the water cut of horizontal wells exceeded 90% in two years. In terms of production characteristics, the main controlling factors of this kind of reservoir production are the development of interlayer and the thickness of water layer. The frequency of seismic data in this area is 0 - 110 Hz, the main frequency is 55 Hz, and the 90-degree phase-shift data show that the thicker reservoirs have multi-axis artifacts. There are many factors affecting the seismic response using conventional amplitude attributes, and there are uncertainties in the identification of thickness and the internal superimposition relationship [7].

3. The Method of Research and Expected Results

Early drilling and drilling proved that the reservoir thickness ranged from 8 to 20 m, in which 60% of the sand body area exceeded 20 m. In this river channel description, by using the characteristics of seismic frequency bandwidth, through wavelet frequency division, statistical correlation between well point thickness and frequency, three kinds of frequencies of medium/high/low are optimized by fusion algorithm, and the final resonance modulation amplitude is determined by matching and verifying well seismic data. By this method, the real response characteristics of ultra-thick reservoir and interval interbeds are restored to the greatest extent, and through later passing wells. Secondly, the harmonic amplitude data volume is processed to extract three frequency data volumes, and the geological bodies with different background frequencies are displayed by RGB three-color superposition, so as to achieve the purpose of describing the structure and distribution characteristics of thick reservoirs. Secondly, the flow units of bottom-water reservoirs are divided by three factors: interlayer, sedimentary barrier and water-oil thickness ratio, which have the greatest impact on bottom-water reservoirs, and by enriching the verification of flooding data. Although there are few well data, according to the general characteristics of reservoirs, this paper expects to divide the distribution range of reservoirs with thickness of 25 m, 15 m and 8 m. The distribution of internal interbeds can be verified by the water cut rise of horizontal wells. Especially the water flooding data of passing wells in the later stage can greatly reduce this uncertainty, thus ensuring the correctness of flow unit division. Because of the strong heterogeneity of reservoirs, the thickness of interbeds is among them. Reservoirs with degrees below 8 m and above 25 m are difficult to describe. In the future, the micro-structure of larger scale and smaller scale can be displayed through frequency depth study, so that the inner structure of flow unit can be accurately clarified.

4. Internal Structure of Thick Sand Layer

The thickness of Um797 sandstone layer varies in different planes. The average sand body in the west is more than 25 m. Affected by the resolution, there are two or even three sets of axes, some of which are similar to the response of interlayer. A11, A28H and A9H drilled-through reservoirs show a complete set of thick layers. The 90-degree phase-shift data show the illusion of interlayer. In the actual research process, it is found that the corresponding relationship between different frequencies and thickness is obvious [8]. Under the background of 2100 m/s seismic velocity, 25 m thick reservoirs correspond to 20 Hz frequency, while 8 m single channel sand body corresponds to 70 Hz. From these frequency bodies, most of them are selected. The neural network inversion under well matching constraints can obtain a better combination of frequency-division data sets, which are in good agreement with well and seismic data. By using this combination of frequency-division data sets to invert harmonic amplitude, seismic data bodies whose thickness can be characterized by reflection thickness can be obtained in the whole area. This method can be used to characterize the profile of ultra-thick reservoir. Compared with 90-degree phase-shift profile, applying this set of data to the characterization of interlayer in thick sand layer can restore the true response characteristics of interlayer in thick sand layer. **Figure 3** is a comparison of the interlayer range depicted by 90-degree phase-shift data and inversion data of harmonic amplitude modulation. After eliminating the false response, the interlayer [9] which has great influence on development is obviously narrowed. The production performance of horizontal wells can be well verified. Taking A67H1/A72H and A78H in areas with low well control degree as examples, the water cut of the three wells breaks through 90% in less than one month, compared with well control. The A63H/A68H region with high degree

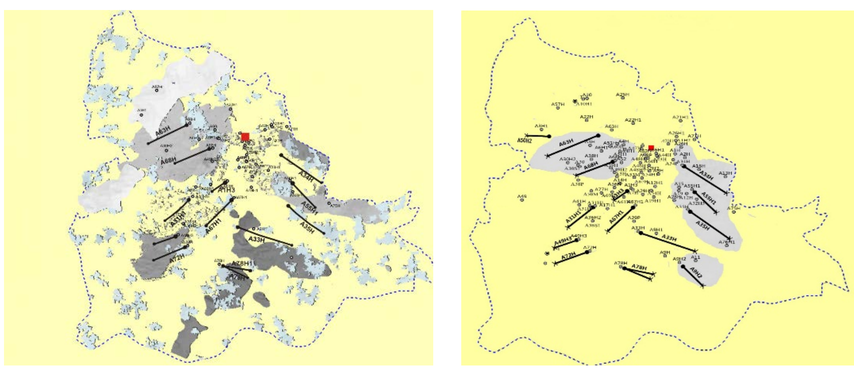

Figure 3. Interlayer diagram characterized by 90-degree phase shift (Left) and resonance modulated amplitude inversion profile (Right).

and interlayer partition is obviously different, and the interlayer range depicted by the inversion method of harmonic amplitude modulation is closer to the real underground situation.

5. Plane Distribution Characteristics of Thick Sand Layer

Conventional amplitude attributes are difficult to characterize reservoirs with excessive thickness, and the whole reservoir is full of sand. In practical research, it is found that on the basis of the data processing of the resonant amplitude, the multi-attribute fusion display based on the frequency division RGB color model can distinguish different thicknesses [10]. The specific operation method is to extract attributes of different frequencies from seismic data, and then generate slices of three attributes for RGB mixed-color display. Three-dimensional seismic data volume is transformed into four-dimensional data volume by frequency division and back to three-dimensional data volume by fusion display, but the boundary between different lithologies is highlighted, and the shape of each lithologic combination geological body is distinguished by color, which is the best imaging method of time-frequency analysis at present. This RGB fusion display method has a good effect on highlighting the energy approximation feature area of each frequency division attribute, and can highlight the commonness and weaken the difference. For the recognition of geological bodies, if the energy characteristics are strong in different frequency bands after frequency division, the geological bodies on the color data volume after RGB mode fusion will show obvious differences with surrounding rock in near white characteristics. As shown in **Figure 4**, using this method, the data are improved obviously. Using RGB attribute fusion attribute slices, the plane contact relationship between geologic bodies with different thickness of Um797 sand body can be clearly seen.

6. Analysis and Classification of Influencing Factors of Flow Units

According to the division of flow units, it is considered that the same flow unit has similar seepage characteristics and similar flooding characteristics. Different flow units have different flooding characteristics and distribution characteristics of remaining oil. For thick reservoirs with bottom water, the main factors affecting flow units are sedimentation and development. For Um797 sand body,

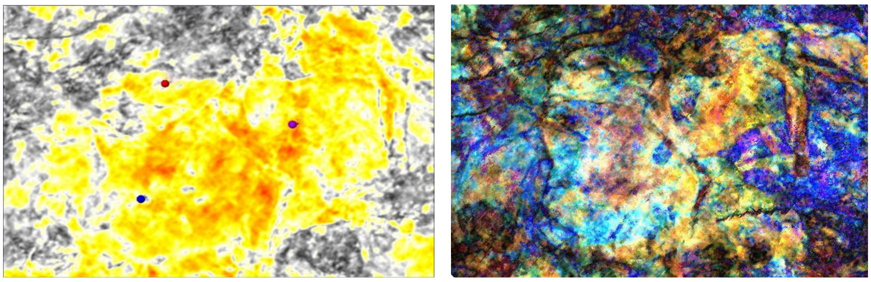

Figure 4. Contrast chart of fusion attribute (Right) between conventional amplitude attribute (Left) and RGB attribute.

because there are no faults in the oilfield, the development of horizontal wells is affected by reservoir boundary, interlayer and water-oil thickness ratio. Secondly, the development of interlayer plays an obvious disturbing role in the rise of bottom water, and lithologic boundary will store in different structures. Layers are divided into different flow units; for the bottom water area with similar reservoir structure, the thickness of water and oil is different from that of different horizontal wells. Especially in the thin bottom water area, horizontal wells have the dual function of bottom water and edge water drive, while the thick bottom water area is mainly characterized by bottom water ridge, and horizontal wells can reach 90% in the fastest one month. According to these three factors, sand bodies are divided into 10 flow units. Yuan, abundant flooding data verify the rationality of the division (**Figure 5**). The overall sand body is divided into three types: the first type is pure oil area, unit 9 is a single channel characteristic, and the water cut of A37H1 reaches 90% only after 2 years; unit 6 is close to the thick bottom water area, and many newly drilled crossing wells show water flooding status; unit 7 and 8 are two stages of channel overlapping area because of the existence of interlayer, and the three newly drilled crossing wells are still in the surrounding horizontal wells after many years of production. The second type is thick bottom water area, because of strong bottom water ridge, the radius of the ridge is only 70 m, and only one passing well near the horizontal well shows that the bottom is flooded 1 m. The second type is thick bottom water area, such as Units 3. Because of the development of interbeds, the duration of low water cut period is relatively long. The third type is thin bottom water area, such as Units 1 and 4. The water cut of horizontal well A78H1 lasts 8 months and reaches 90%. Generally speaking, the flooding situation of newly drilled passing wells confirms the distribution characteristics of remaining oil, which mainly distributes in the top of reservoir and the bottom of interlayer in strong bottom water wells and weak bottom water areas.

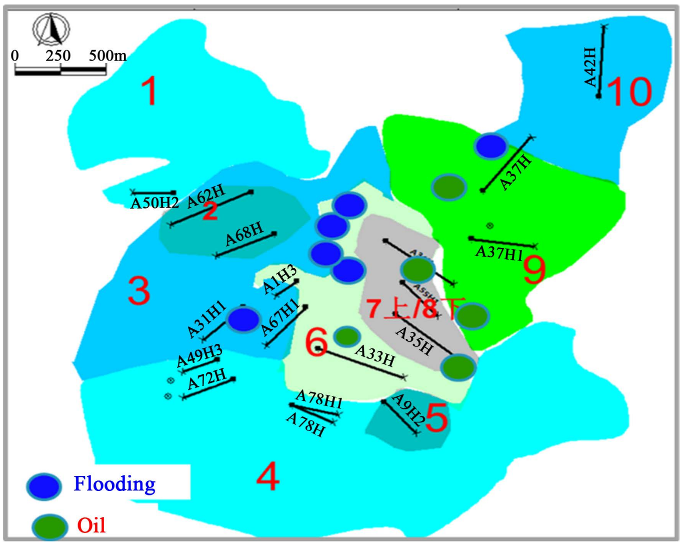

Figure 5. Flow unit diagram of Um797 sand body.

7. The Effect of Development Practice

Five horizontal wells are deployed in the interlayer and thin bottom water area. The average low water cut period lasts for one and a half years when the water avoidance height is obviously reduced. A50H2 is a newly drilled adjustment well, located in the thin bottom water area, about 160 m away from the old well, and the water cut is still below 80% in 5 months when the water avoidance height is only 8.4 m, and the oil production is nearly 100 square/day. That is, the situation of high water cut. Considering that horizontal wells in thin bottom water area have dual functions of water ridge and lateral oil displacement, A33H well is selected to make the greatest liquid extraction attempt in this offshore oilfield. The effect is obvious. The liquid volume is increased from 1700 to 2700, the oil production is increased from 45 to 125 square per day, and the water cut is reduced by 1.4%.

8. Conclusions

In this paper, the resonance amplitude modulation technique is applied to restore the true response characteristics of thick sand body. On this basis, the frequency division RGB fusion technique is applied to identify reservoir ranges with different thickness. On this basis, the geophysical prospecting method of thick bottom water reservoir-sedimentary genesis-flow unit division method is established by using reservoir boundary, interlayer and water-oil thickness ratio. It is under the condition of high cost drilling in offshore oilfields. Through this research result, adjusting wells can be precisely implemented in thin bottom water or interlayer area, and large-scale fluid extraction can be carried out, which can effectively reduce the development risk. This research result has strong practicability and can be further promoted in similar oilfields.

It should be pointed out that this technique has some limitations, such as that the flow units caused by the smaller 3-level and 4-level interfaces in the thick sand body need to be identified by more drilling and even core data, and the deep excavation frequency data are also needed to realize the smaller-scale flow unit division. With the large-scale adjustment of offshore oilfields in the later stage, more abundant flow units can be obtained. Static data are further excavated.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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